Application of Bio-Inspired Optimization Technique for Finding the Optimal set of Concentric Circular Antenna Array with Central Element Feeding

Durbadal Mandal[1], Bipul Goswami[1], Rajib Kar[1], Sakti Prasad Ghoshal[2] and Anup Kr. Bhattacharjee[1]
[1]Department of Electronics and Communication Engineering.
[2]Department of Electrical Engineering.
National Institute of Technology Durgapur
West Bengal, India- 713209
Email: {durbadal.bittu, goswamibipul, rajibkarece, spghoshalnitdgp}@gmail.com, akbece12@yahoo.com

Abstract- **In this paper the maximum sidelobe level (SLL) reductions of three-ring concentric circular antenna arrays (CCAA) without and with central element feeding are examined using two different classes of evolutionary optimization techniques to finally determine the global optimal three-ring CCAA design. Apart from physical construction of a CCAA, one may broadly classify its design into two major categories: uniformly excited arrays and non-uniformly excited arrays. The present paper assumes non-uniform excitations and uniform spacing of excitation elements in each three-ring CCAA design and a design goal of maximizing SLL reduction associated with optimal beam patterns and beam widths. The design problem is modeled as an optimization problem for each CCAA design. Binary coded Genetic Algorithm (BGA) and Bacteria Foraging Optimization (BFO) are used to determine an optimum set of normalized excitation weights for CCAA elements, which, when incorporated, results in a radiation pattern with optimal (maximum) SLL reduction. Among the various CCAA designs the three-ring CCAA containing (N_1=4, $N_{2=}$6, N_3=8) elements along with central element feeding proves to be global optimal design. BFO yields global minimum SLL (-34.18 dB) and global minimum BWFN (81.5^0) for the optimal design.**

Index Terms- **Bacteria Foraging Optimization (BFO); Binary coded Genetic Algorithm (BGA); Concentric Circular Antenna Array (CCAA); First null beamwidth (BWFN); Non-uniform Excitation; Sidelobe Level (SLL).**

I. Introduction

An antenna array consists of multiple stationary antenna elements, which are often fed coherently. Recently, varied applications of antenna array have been suggested to improve the performance of mobile and wireless communication systems through efficient spectrum utilization, increasing channel capacity, extending coverage area, tailoring beam shape etc. However, arbitrary array design may lead to increment in pollution of the electromagnetic environment and more importantly, wastage of precious power, which may prove fatal for power-limited battery-driven wireless devices. This explains the presence of abundant open technical literatures [1-12], bearing a common target - bridging the gap between desired radiation pattern with what is practically achievable.The primary method in all these research works is betterment of array pattern by manipulating the structural geometry to suppress the sidelobe level (SLL) while preserving the gain of the main beam. The goal in such antenna array geometry synthesis techniques is to determine the physical layout of the array that produces the radiation pattern closest to the desired pattern. As the shape of the desired pattern can vary widely depending on the application, many synthesis methods coexist.

Among the different types of antenna arrays CCAA [8, 9, 11] have become most popular in mobile and wireless communications. This very fact has inspired the design of CCAA and evaluation of the performance of corresponding antenna arrays. In this paper optimization of CCAA design having uniform inter-element separations and non-uniform excitations (to be optimized) is performed with the help of a novel Bio-inspired optimization technique (BFO) [13-15] and BGA [10, 15]. The array factors due to optimal non-uniform excitations in various CCAA design structures are examined to find the best possible design structure. Regarding the comparative effectiveness of the techniques, the newly proposed BFO technique proves to be better in attaining minimum SLL, reduction of major lobe beamwidth and hence minimum “Misfitness” objective function values in the optimization of various CCAA designs.

The paper is arranged as follows: In section II, the general design equations for the non-uniformly excited CCAA are stated. Then, in section III, brief introductions for the BGA and BFO are presented. Numerical results are presented in section IV. Finally the paper concludes with a summary of the work in section V.

II. Design Equation

Geometrical configuration is a key factor in the design process of an antenna array. The geometry controls radiation pattern and almost all other important factors of array antenna. For CCAA, the elements are arranged in such a way that all antenna elements are placed in multiple concentric circular rings, which differ in radii and in number of elements.Fig. 1 shows the general configuration of CCAA with M concentric circular rings, where the m^{th} ($m = 1, 2,\ldots, M$)

DOI: 01.IJIT.02.02. 64

ring has a radius r_m and the corresponding number of elements is N_m. If all the elements (in all the rings) are assumed to be isotopic sources, then the radiation pattern of this array can be written in terms of its array factor only.

Referring to Fig.1, the array factor, $AF(\phi, I)$ for the CCAA in *x-y* plane is expressed as (1) [8]:

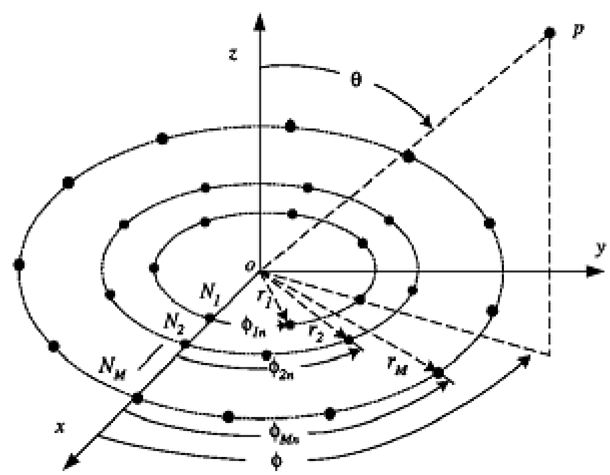

Figure 1. Concentric circular antenna array (CCAA).

$$AF(\phi, I) = \sum_{m=1}^{M} \sum_{i=1}^{N_m} I_{mi} \exp\left[j\left(kr_m \sin\theta \cos(\phi - \phi_{mi}) + \alpha_{mi}\right)\right] \quad (1)$$

where, I_{mi} denotes current excitation of the i^{th} element of the m^{th} ring, $k = 2\pi/\lambda$; λ being the signal wave-length, and θ and ϕ symbolize the zenith angle from the positive *z* axis and the azimuth angle from the positive *x* axis to the orthogonal projection of the observation point respectively. It may be noted that if the elevation angle is assumed to be 90 degrees i.e. $\theta = 90^0$ then (1) may be written as a periodic function of ϕ with a period of 2π radians. The angle ϕ_{mi} is element to element angular separation measured from the positive *x* axis. As the elements in each ring are assumed to be uniformly distributed, ϕ_{mi} may be written as:

$$\phi_{mi} = 2\pi\left(\frac{i-1}{N_m}\right); \quad m = 1, \ldots, M; \quad i = 1, \ldots, N_m \quad (3)$$

where ϕ_0 is the value of ϕ where the peak of the main lobe is obtained.

After defining the array factor, the next step in the design process is to formulate the objective function which is to be minimized. As it is a minimization problem, so fitness function may be considered as the "Misfitness" (MF) objective function, which may be written as:

$$MF = W_{F1} \times \frac{\left|AF(\phi_{msl1}, I_{mi}) + AF(\phi_{msl2}, I_{mi})\right|}{\left|AF(\phi_0, I_{mi})\right|} + W_{F2} \times \left(BWFN_{computed} - BWFN(I_{mi} = 1)\right) \quad (4)$$

BWFN is an abbreviated form of first null beamwidth, or, in simple terms, angular width between the first nulls on either side of the main beam. MF is computed only if $BWFN_{computed} < BWFN(I_{mi} = 1)$ and corresponding solution of current excitation weights is retained in the active population otherwise not retained. W_{F1} and W_{F2} are the weighting factors. ϕ_0 is the angle where the highest maximum of central lobe is attained in $\phi \in [-\pi, \pi]$. ϕ_{msl1} is the angle where the maximum sidelobe $(AF(\phi_{msl1}, I_{mi}))$ is attained in the lower band and ϕ_{msl2} is the angle where the maximum sidelobe $(AF(\phi_{msl2}, I_{mi}))$ is attained in the upper band. are so chosen that optimization of SLL remains more dominant than optimization of and never becomes negative.

After experimentation, best proven values of are fixed as 18 and 1 respectively. In (4) the two beamwidths, and basically refer to the computed first null beamwidth in radian for the non-uniform excitation case and for uniform excitation case respectively. Minimization of means maximum reductions of SLL both in lower and upper bands and lesser as compared to . The evolutionary optimization techniques employed for optimizing the current excitation weights resulting in the minimization of and hence reductions in both SLL and *BWFN* are described in the next section.

III. Evolutionary Techniques Employed

A. *Binary coded Genetic Algorithm (BGA)*

GA is mainly a probabilistic search technique, based on the principles and concept of natural selection and evolution. At each generation it maintains a population of individuals where each individual is a coded form of a possible solution of the problem at hand and called chromosome. Chromosomes are constructed over some particular alphabet, e.g., the binary alphabet [0, 1], so that chromosomes' values are uniquely mapped onto the decision variable domain. Each chromosome is evaluated by a function known as fitness function, which is usually the cost function or the objective function of the corresponding optimization problem. Steps of BGA as implemented for optimization of current excitation weights are adopted from [15].

B. *Bacteria Foraging Optimization (BFO)*:

Steps of BFO as implemented for optimization of current excitation weights are adopted from [15].

IV. Experimental Results

This section gives the experimental results for various CCAA designs obtained by BGA and BFO techniques. For each optimization technique ten three-ring (M=3) CCAA structures are assumed. Each CCAA maintains a fixed spacing between the elements in each ring (inter-element spacing being

DOI: 01.IJIT.02.02.64

0.55ë, 0.61ë and 0.75ë for the first ring, the second ring and the third ring respectively). These spacings are the means of the values determined for the ten structures for non-uniform inter-element spacing and non-uniform excitations in each ring using 25 trial generalized optimization runs for each structure. For all sets of experiments, the number of elements for the inner most ring is N_1, for outermost ring is N_3, whereas the middle ring consists of N_2 number of elements. For all the cases, $\phi_0 = 0^0$ is considered so that the centre of the main lobe in radiation patterns of CCAA starts from the origin.

The following best proven parameters are

(a) for BGA:

i) Initial population, n_p = 120 chromosomes ii) Maximum number of genetic cycles = 3000, iii) Selection probability, Crossover (dual point) ratio and mutation probability = 0.3, 0.8 and 0.004 respectively, and

(b) for BFO:

i) $\max_{reprod} = 90$, ii) $\max_{chemo} = 120$, iii) $\max_{dispersal} = 2$, iv) $numBact = 120$, v) $d_{attract} = 1.0$, vi) $w_{attract} = 0.1$, vii) $d_{repelent} = 1.0$, viii) $w_{repelent} = 0.1$, ix) $s_r = 0.3$, x) $P_{ed} = 0.3$, xi) $c_{\max} = 0.1$, xii) $c_{\min} = 0.01$, xiii) $d_1 = 0.01$, xiv) $d_2 = 0.01$, xv) $\max_{swim} = 4$.

Each BGA and BFO generates a set of normalized non-uniform current excitation weights for each set of CCAA. I_{mi} =1 corresponds to uniform current excitation. Sets of three-ring CCAA (N_1, N_2, N_3) designs considered for both without and with central element feeding are (2,4,6), (3,5,7), (4,6,8), (5,7,9), (6,8,10), (7,9,11), (8,10,12), (9,11,13), (10,12,13) and (11,13,15). Some of the optimal results for BGA and BFO are shown in Tables II-V. Table I depicts SLL values and BWFN values for all corresponding CCAA structures but uniformly excited (=1).

A. Analysis of Radiation Patterns of CCAA

Figs. 2-3 depict the substantial reductions in SLL with non-uniform optimal current excitations as compared to the case of uniform non-optimal current excitations. All CCAA sets having central element feeding (Case (b)) yield much more reductions in SLL as compared to the same not having central element feeding (Case (a)). As seen from Tables II-V, SLL reduces to -26.14 dB (BGA), -29.96 dB (BFO) for Case (a) and -29.06 dB (BGA), *-34.18 dB (grand highest SLL reduction as determined by BFO for Case (b), shown as a shaded row in Table V) for the CCAA having N_1=4, N_2=6, N_3=8 elements* (Set No. III). This optimal set along with central element feeding yields grand maximum SLL reductions for both techniques among all the sets.

BWFN values become less for non-uniform optimal current excitations as compared to the case of uniform non-optimal excitations for all design sets in both the cases. For the same optimal CCAA set, the BWFN values are 73.6^0 (BGA) and 75.8^0 (BFO) for Case (a), 78.3^0 (BGA) and 81.5^0 (BFO) for Case (b) against 90.3^0 (Case (a)), 95.4^0 (Case (b)) for the corresponding uniformly excited CCAA having the same number of elements. So, these techniques yield maximum reductions of BWFN also for this optimal CCAA.

From Tables II-V, it is observed that as compared to BGA, BFO always yields higher SLL reductions for all the CCAA sets.

In Figures 4-5, the minimum MF values are plotted against the number of iteration cycles to get the convergence curves for BGA and BFO respectively. Table VI as well as Figures 4-5 show BFO yields optimal (least) values consistently in all cases. With a view to the above facts, it may finally be inferred that BFO yields better optimization than BGA. All computations were done in MATLAB 7.5 on core (TM) 2 duo processor, 3.00 GHz with 2 GB RAM

TABLE I. SLL And BWFN For Uniformly Excited (I_{mi} =1) CCAA Sets

Set No.	No. of elements in each rings (N_1,N_2,N_3)	Without central element (Case (a))		With central element (Case (b))	
		SLL (dB)	BWFN (deg)	SLL (dB)	BWFN (deg)
I	2, 4, 6	-12.56	128.4	-17.0	140.0
II	3, 5, 7	-13.8	107.2	-15.0	116
III	4, 6, 8	-11.23	90.3	-12.32	95.4
IV	5, 7, 9	-11.2	78.2	-13.24	81.6
V	6, 8, 10	-10.34	68.4	-12.0	71.1
VI	7, 9, 11	-10.0	61.0	-11.32	63.0
VII	8, 10, 12	-9.6	54.8	-10.76	56.4
VIII	9, 11, 13	-9.28	50.0	-10.34	51.3
IX	10, 12, 14	-9.06	46.0	-10.0	47.0
X	11, 13, 15	-8.90	42.0	-9.8	43.2

TABLE II. Current Excitation Weights, SLL and BWFN For Non-Uniformly Excited CCAA Sets (Case (a)) Using BGA

Set No.	(I_{11}, I_{12} ,....., I_{mi})	SLL (dB)	BWFN (deg)
I	0.8398 0.9727 0.8242 0.9180 0.8711 0.7969 0.6992 0.7422 0.1680 0.7305 0.6836 0.1680	-23.04	112.7
III	1.0000 0.9450 0.7463 1.0000 0.6799 0.7126 1.0000 0.6068 0.6864 1.0000 0.6021 1.0000 0.6803 0.2289 0.6721 0.8732 0.5849 0.1872	-26.14	73.6
V	0.9219 0.7227 0.8711 0.5781 0.5352 0.9805 0.9922 0.2500 0.8438 0.6094 0.5898 0.2539 0.5977 0.8984 0.1523 0.8672 0.8086 0.2461 0.4844 0.4414 0.5000 0.4883 0.8750 0.5313	-21.62	60.4
VII	0.5898 0.5078 0.8164 0.9492 0.7227 0.3711 0.8086 0.9922 0.6875 0.1055 0.0742 0.6055 0.4570 0.9063 0.1836 0.2656 0.6211 0.5391 0.5938 0.4531 0.8711 0.5000 0.5469 0.5117 0.2461 0.4961 0.9570 0.429 0.2422 0.4570	-24.0	49.5

DOI: 01.IJIT.02.02. 64

TABLE III. CURRENT EXCITATION WEIGHTS, SLL AND BWFN FOR NON-UNIFORMLY EXCITED CCAA SETS (CASE (B)) USING BGA

Set No.	$(I_{11}, I_{12}, \ldots, I_{mi})$	SLL (dB)	BWFN (deg)
I	0.2137 0.9772 0.9385 0.7990 0.7109 0.8336 0.7841 0.5709 0.6021 0.2017 0.5120 0.4711 0.2533	-25.74	137.4
III	0.3789 0.7344 0.9766 0.8164 0.9922 0.7148 0.5508 0.9727 0.7969 0.9102 0.9805 0.6680 0.8750 0.6523 0.1406 0.6406 0.9063 0.5508 0.1680	-29.06	78.3
V	0.4961 0.7500 0.4375 0.7422 0.7891 0.4219 0.4961 0.5703 0.1719 0.7344 0.7461 0.5117 0.5000 0.4492 0.7969 0.1992 0.6797 0.7109 0.4648 0.3203 0.3008 0.8125 0.6055 0.3438 0.3711	-23.34	57.9
VII	0.4570 0.5625 0.8359 0.6328 0.9961 0.8633 0.7969 0.7734 0.9805 0.5000 0.2500 0.1641 0.8398 0.2422 0.8750 0 0.0781 0.8750 0.4258 0.5234 0.1094 0.8711 0.3828 0.2148 0.2891 0.0938 0.6016 0.8711 0.4805 0.1641 0.3750	-25.92	51.6

TABLE IV. CURRENT EXCITATION WEIGHTS, SLL AND BWFN FOR NON-UNIFORMLY EXCITED CCAA SETS (CASE (A)) USING BFO

Set No.	$(I_{11}, I_{12}, \ldots, I_{mi})$	SLL (dB)	BWFN (deg)
I	1.0000 1.0000 1.0000 0.8230 1.0000 0.9564 0.7241 0.6952 0 0.8775 1.0000 0	-24.36	109.2
III	0.2650 0.7067 0.2775 0.8140 0.5534 0.4580 1.0012 0.4423 0.5022 1.0118 0.5253 0.7715 0.5026 0.2103 0.4977 0.7775 0.5300 0.2670	-29.96	75.8
V	0.4707 0.5337 0.8847 0.3531 0.5735 0.4958 0.7334 -0.1839 1.0287 1.0349 0.8497 -0.1361 0.6751 0.9923 0.3592 0.8146 0.8242 0.6011 0.6238 0.5394 0.6991 0.8592 0.2932 0.4811	-25.66	60.6
VII	0.6683 0.3870 0.6763 0.9304 0.8435 0.2870 0.8482 0.8297 0.4225 0.2291 0.1752 0.7041 0.5939 0.7964 0.0415 0.1433 0.7064 0.5031 0.4834 0.2556 0.9753 0.3099 0.3489 0.4069 0.2545 0.4802 1.0080 0.4197 0.4043 0.5836	-26.70	51.66

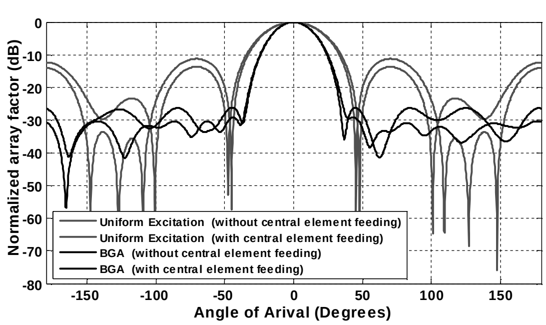

Figure 2. Radiation patterns for a uniformly excited CCAA and corresponding BGA based non- uniformly excited CCAA Set III.

TABLE V. CURRENT EXCITATION WEIGHTS, SLL AND BWFN FOR NON-UNIFORMLY EXCITED CCAA SETS (CASE (B)) USING BFO

Set No.	$(I_{11}, I_{12}, \ldots, I_{mi})$	SLL (dB)	BWFN (deg)
I	0.3853 1.0000 0.9998 0.8841 0.8091 0.9412 0.7628 0.5455 0.5579 0.2288 0.5241 0.5031 0.2524	-26.24	140.0
III	0.3609 0.6028 0.9163 0.6788 0.8340 0.5721 0.6746 0.8466 0.6441 0.6551 0.7818 0.5442 0.6459 0.5636 0.1893 0.5620 0.7443 0.5279 0.1875	**-34.18**	81.5
V	0.5196 0.4313 0.4426 0.8174 0.6304 0.5531 0.4738 0.4296 0.0897 0.8271 1.0000 0.7299 0.1726 0.6097 0.8877 0.3786 0.6737 0.8284 0.4055 0.4689 0.2985 0.9585 0.9349 0.2239 0.4705	-27.46	59.94
VII	0.4843 0.6041 0.7601 0.6925 1.0000 0.6276 0.5796 0.5588 0.8116 0.6700 0.1020 0.0728 0.8969 0.4503 0.8314 0.0552 0.0320 0.4502 0.3777 0.3405 0.3603 1.0000 0.4081 0.3346 0.4107 0.3382 0.5255 0.8106 0.3112 0.3776 0.3991	-28.12	53.46

TABLE VI. MINIMUM MF VALUES OF BGA AND BFO

Set No.	BGA		BFO	
	CASE (a)	CASE (b)	CASE (a)	CASE (b)
I	2.8500	2.7144	2.2173	2.5718
III	2.0230	1.0183	1.1334	0.8164
V	2.9719	1.3786	1.8203	1.1238
VII	2.7018	1.2472	1.7531	1.0610

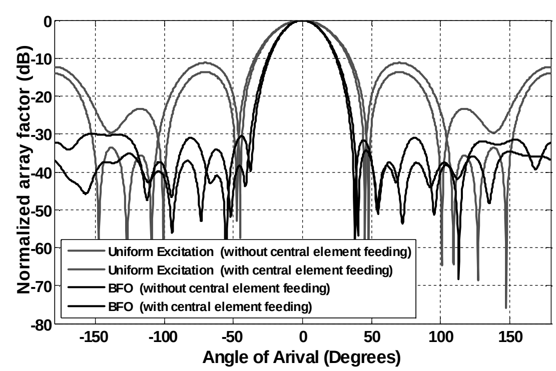

Figure 3. Radiation patterns for a uniformly excited CCAA and corresponding BFO based non- uniformly excited CCAA Set III.

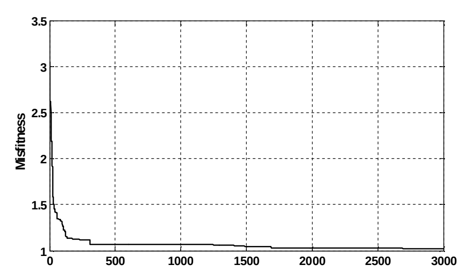

Figure 4. Convergence curve for BGA in case of non-uniformly excited CCAA Set III with central element feeding.

DOI: 01.IJIT.02.02. 64

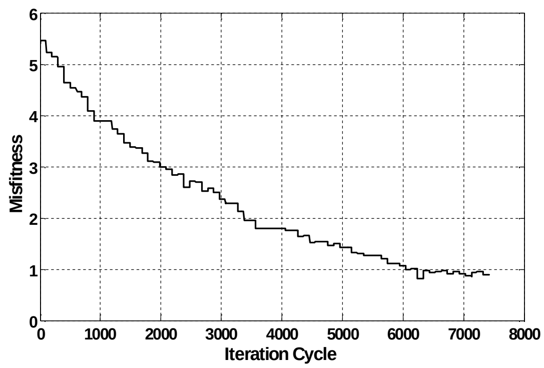

Figure 4. Convergence curve for BFO in case of non-uniformly excited CCAA Set III with central element feeding.

CONCLUSION

In this paper, the design of a non-uniformly excited concentric circular antenna array with uniform spacing between the elements has been described using the techniques of BGA and BFO. BFO technique proves to be robust technique; yields optimal excitations and global minimum values of SLL for all sets of CCAA designs. BGA is less robust and yield suboptimal results. Experimental results reveal that the optimal design of non-uniformly excited CCAA offers a considerable SLL reduction along with the reduction of BWFN with respect to the corresponding uniformly excited CCAA. The main contribution of the paper is threefold: (i) All CCAA designs having central element feeding yield much more reductions in SLL as compared to the same not having central element feeding, (ii) The CCAA set having N_1=4, N_2=6, N_3=8 elements along with central element feeding gives the grand maximum SLL reduction (-34.18 dB) as compared to all other sets, which one is thus the grand optimal set among all the three-ring structures, and (iii) Comparing the performances of both techniques BFO shows better optimization performance as compared to BGA in the optimal design of three-ring CCAA.

REFERENCES

[1] C. Stearns and A. Stewart, "An investigation of concentric ring antennas with low sidelobes," *IEEE Trans. Antennas Propag*.,vol. 13, no. 6, pp. 856–863, Nov. 1965.

[2] R. Das, "Concentric ring array," *IEEE Trans. Antennas Propag*., vol. 14, no. 3, pp. 398–400, May 1966.

[3] N. Goto and D. K. Cheng, "On the synthesis of concentric-ring arrays," *IEEE Proc*., vol. 58, no. 5, pp. 839–840, May 1970.

[4] L. Biller and G. Friedman, "Optimization of radiation patterns for an array of concentric ring sources," *IEEE Trans. Audio Electroacoust*., vol. 21, no. 1, pp. 57–61, Feb. 1973.

[5] M D. A. Huebner, "Design and optimization of small concentric ring arrays," in *Proc. IEEE AP-S Symp*., 1978, pp. 455–458.

[6] M G. Holtrup, A. Margulnaud, and J. Citerns, "Synthesis of electronically steerable antenna arrays with element on concentric rings with reduced sidelobes," in *Proc. IEEE AP-S Symp*., 2001, pp. 800–803.

[7] M. A. Panduro, A. L. Mendez, R. Dominguez and G. Romero, "Design of non-uniform circular antenna arrays for side lobe reduction using the method of genetic algorithms," *Int. J. Electron. Commun. (AEÜ)* vol. 60 pp. 713 – 717, 2006.

[8] R. L. Haupt, "Optimized element spacing for low sidelobe concentric ring arrays," *IEEE Trans. Antennas Propag*., vol. 56(1), pp. 266–268, Jan. 2008.

[9] R. Fallahi and M. Roshandel, "Effect of mutual coupling and configuration of concentric circular array antenna on the signal-to-interference performance in CDMA systems," *Progress In Electromagnetics Research*, vol. PIER 76, pp. 427–447, 2007.

[10] R. L. Haupt, and D. H. Werner, Genetic Algorithms in Electromagnetics, IEEE Press Wiley-Interscience, 2007.

[11] M. Dessouky, H. Sharshar, and Y. Albagory, "Efficient sidelobe reduction technique for small-sized concentric circular arrays," *Progress In Electromagnetics Research*, vol. PIER 65, pp. 187–200, 2006.

[12] K. -K. Yan and Y. Lu, "Sidelobe Reduction in Array-Pattern Synthesis Using Genetic Algorithm," *IEEE Trans. Antennas Propag*., vol. 45(7), pp. 1117-1122, July 1997.

[13] K. M. Passino, "Biomimicry of bacteria foraging for distributed automation and control," IEEE Control System Magazine, pp. 52–67, 2002.

[14] S. P. Ghoshal, A. Chatterjee and V. Mukherjee "Bio-inspired fuzzy logic based tuning of power system stabilizer," Expert Systems with Applications vol. 36 (5) pp. 9281–9292, July 2009.

[15] D. Mandal, S. P. Ghoshal, and A. K. Bhattacharjee, "Application of Bio-Inspired Optimization Technique for Finding The Optimal set of Concentric Circular Antenna Array," *2009 World Congress on Nature & Biologically Inspired Computing*, pp. 1247-1252, 2009

DOI: 01.IJIT.02.02. 64